Multi-photon structures in the sub-cyclotron-frequency range in microwave photoresistance of a two-dimensional electron system

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The frequency dependence of the peak-valley pairs occurring in the magnetoresistivity of a two-dimensional electron system under enhanced microwave irradiation, which are considered to associate with multiphoton processes, is examined in the sub-cyclotron-frequency range, based on a theoretical treatment with photon-assisted electron transitions due to impurity scattering. It is shown that with equivalent radiation power (producing the same height of the main oscillation peak), much more and stronger multi-photon structures show up at lower frequency, and when frequency increases all these structures rapidly weaken, diminish and finally disappear completely. These are in agreement with the recent experimental observation [cond-mat/0608633].

The microwave-induced magnetoresistance oscillations (MIMOs) in high-mobility two-dimensional (2D) electron systems[1,2,3,4,5,6] continue to be a phenomenon of great interest. In addition to well-established main oscillations featuring large maximum-minimum pairs, secondary peak-valley structures were also observed in the early experiments[4,5,6], and predicted theoretically[7,8], referred to the effect of two- and three-photon processes. Later experimental and theoretical investigations with enhanced radiation intensity or reduced radiation frequency disclosed further details of these structures.[9,10,11,12,13,14,15]

Motivated by a recent measurement of MIMOs at the subharmonics of cyclotron resonance,[16] we performed further examination using the balance-equation approach[8,14] with photon-assisted electron transitions due to impurity scattering. Some results obtained by taking the same material parameters as those in Ref. [15], are presented here.

Figure 1 shows the calculated magnetoresistivity R_{xx} as a function of ω_c/ω (ω_c is the cylotron frequency) for a GaAs-based 2D system having electron density $N_{\rm e}$ = $3.0 \times 10^{15}\,\mathrm{m}^{-2}$, linear mobility $\mu_0 = 2000\,\mathrm{m}^2/\mathrm{Vs}$ and broadening parameter $\alpha = 5$, irradiated by microwaves of frequency $\omega/2\pi = 50\,\mathrm{GHz}$ having three incident amplitudes $E_{\rm i} = 6, 8$ and $10\,\mathrm{V/cm}$ at lattice temperature $T = 1\,\mathrm{K}$. Prominent valley-peak pairs show up around $\omega_c/\omega = 2$ and 1.5 for all three radiation strengths, and $\omega_c/\omega = 2$ appears to be a node point with almost zero resistivity response to these amplitude change.

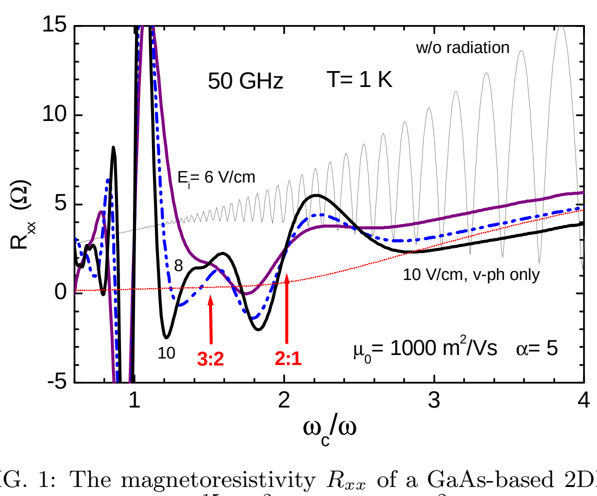

FIG. 1: The magnetoresistivity R_{xx} of a GaAs-based 2DEG with $N_{\rm e} = 3.0 \times 10^{15}\,\mathrm{m}^{-2}$, $\mu_0 = 2000\,\mathrm{m}^2/\mathrm{Vs}$ and $\alpha = 5$, subjected to 50 GHz radiations of incident amplitudes $E_{\rm is} = 6, 8$ and $10\,\mathrm{V/cm}$ at lattice temperature $T = 1\,\mathrm{K}$.

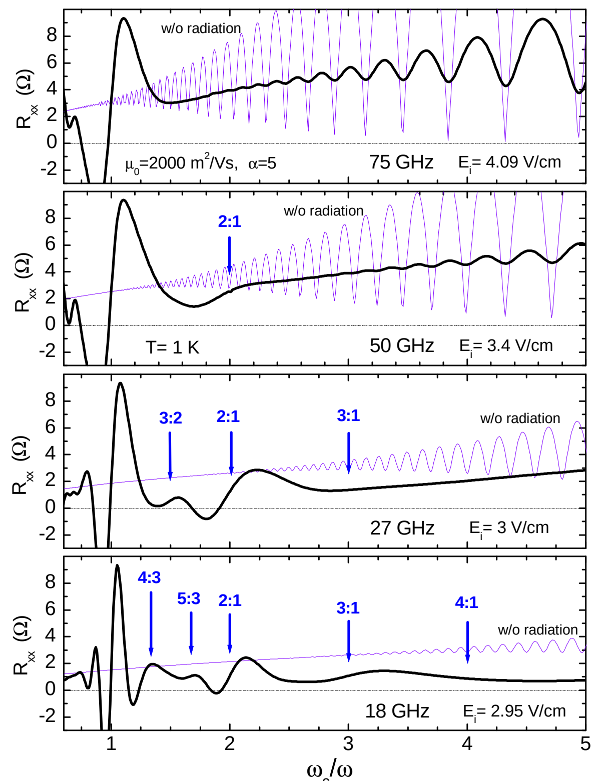

FIG. 2: The Magnetoresistivity R_{xx} of a GaAs-based 2DEG with $N_{\rm e} = 3.0 \times 10^{15}\,\mathrm{m}^{-2}$, $\mu_0 = 2000\,\mathrm{m}^2/\mathrm{Vs}$ and $\alpha = 5$, subjected to radiations of frequencies $\omega/2\pi = 18, 27, 50$ and $75\,\mathrm{GHz}$ with incident amplitudes $E_{\rm i} = 2.95, 3, 3.4$ and $4.09\,\mathrm{V/cm}$ respectively, at lattice temperature $T = 1\,\mathrm{K}$.

Figure 2 illustrates the effect of different radiation frequencies on these fine structures associated with mul-

tiphoton assisted processes for the same system as described in Fig. 1. The radiation strength at each frequency is so chosen that almost the same height of the main oscillation peak (around $\omega_c/\omega = 1$) is obtained for all four frequencies. However, the valley-peak structures around $\omega_c/\omega = 2, 3/2, 3, 4/3$ and 4, which show up prominently at 18 GHz, weaken or diminish at 27 GHz, become barely appreciable only around $\omega_c/\omega = 2$ at 50 GHz, and completely disappeared at 75 GHz.

It is also seen from both figures that the average of all the resistivity curves with strong irradiation drop down below the that of dark curve in the sub-cyclotron-frequency range .

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